Electronics Division Technical Note No. 221

Modular Analysis Software for the ALMA Front End Test and Measurement System

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Abstract: A new software library for The ALMA Front End Test and Measurement System (FETMS) will be implemented at the NRAO Technology Center (NTC) to test new front end systems. This library will ensure that these front end systems meet noise temperature specifications and IF output power spectrum specifications, allowing optimal signal-to-noise ratios (SNR) to be made with the receivers. The library is written in PHP and is used to find, analyze, and display test data from FETMS measurements database. It features structured interfaces for simple communication between tests, flexible database retrieval to minimize computation time, universal data structures which utilize the PHP array features to allow for ease in data manipulation, and an adaptable plotter class that gives the user a simple module to plot their data. These features will allow for easier use, quicker maintenance, and more timely upgrades. This library is now running on the FETMS at the NTC and future versions will include more specification test options and the removal of possible bugs.

1. Introduction

The Atacama Large Millimeter/ Sub-millimeter Array (ALMA) Front End Test and Measurement System (FETMS) is used to test the components of each front end against pre-determined specifications to give astronomers the high sensitivity needed to achieve quality observations. This new software to be used by the FETMS focuses on noise temperature measurements and intermediate frequency (IF) output measurements.

2. Specification Tests

2.1. Noise Temperature

Noise temperature refers to the noise added to a signal by the components in the receiver. In order to minimize this effect, the receiver uses Superconductor-Insulator-Superconductor (SIS) mixers, which contribute small amounts of noise to the signal compared to High-Electron-Mobility transistor (HEMT) amplifiers working at the same frequencies (84 GHz to 962 GHz for bands 3-10), and must be cooled to 4 K. In order to assure a noise temperature upper limit, a signal is split between its polarizations and sidebands (outputting 4 signals), all of which measure the total down-converted RF power of a liquid nitrogen bath (~80 K), and a chopper blade at room temperature (~300 K), which is covered in AN-72 millimeter-wave absorber material. This is done by using a local oscillator (LO) that is tuned to the frequency of the desired signal, allowing the receiver to collect the power of the chopper or bath. The ratio of the measured powers is then equated to a Y factor:

$$Y = \frac{P_{hot}}{P_{cold}}$$

P_{hot} and P_{cold} are the powers measured of the chopper and the liquid nitrogen bath, respectively. This factor can then be used to derive a receiver temperature with the following equation:

$$T_{rx} = \frac{T_{amb} - T_{cold} * Y}{Y - 1}$$

T_{amb} is the ambient temperature of the chopper and T_{cold} is the effective cold load temperature, which is the liquid nitrogen temperature corrected for losses mainly caused by the mirror reflecting the radiation to the receiver. This temperature is then corrected for image rejection, which is the ratio of a model and image signals at a specific frequency, with the following equation:

$$T_{SSB} = T_{rx}(1 + 10^{\frac{-|IR|}{10}})$$

IR is the image rejection value with units dB (decibels). This corrected noise temperature, T_{SSB}, is then compared to the results of the same measurement provided by the cartridge manufacturer. The percent difference, relative to the specification, in this comparison should be as close to 0 as possible, and is shown in Figure 1. The corrected noise temperature is also compared to the IF range for the LO, and must lie below an upper limit, which differs by band. This comparison is shown in Figure 2 and the effective cold load temperature, IF range, and noise temperature limits are shown in Table 1.

Band	Eff. Cold Load Temp (K)	IF Lower Limit (GHz)	IF Upper Limit (GHz)	100% Temp Limit (K)	80% Temp Limit (K)
1	78.8	4	12	26	17
2	78.8	4	12	47	17
3	77.35	4	8	60	39
4	80.1	4	8	82	51
5	80.1	4	8	105	65
6	79.1	5	10	136	83
7	78.1	4	8	219	147
8	78.2	4	8	292	196
9	78.2	4	12	261	175
10	83.3	4	12	344	230

Table 1- This table shows the effective cold load temperatures (K), IF ranges (GHz), and noise temperature upper limits (K) for each band in the ALMA front end. The 100% limit covers any RF frequency while the 80% limit covers 80% of the RF band.

2.2 IF Output Spectrum

The IF Output Spectrum test looks at the IF output power spectrum of the receiver over its specified IF range. The raw data is collected by using a spectrum analyzer, which uses 6,000 points over a frequency range from 0 to 18 GHz. The analyzer has a resolution bandwidth (RBW) of 3 MHz and a video bandwidth (VBW) of 3 kHz, along with an attenuation of 5 dB. The test then takes the output power spectrum and checks for spikes, which will translate to spikes in the final spectrum and can imitate or increase the strength of spectral lines, which will lead to mistakes made in the science following the observations. These tests also look at the power variation (difference between the maximum and minimum power) over either a 2 GHz or 31 MHz window, where the variation must lie beneath 6 dB and 1.35 dB respectively. This variation could cause spectral lines in the final spectrum to appear relatively stronger or weaker if these variations are too large. These tests can be seen in Figures 3 and 4.

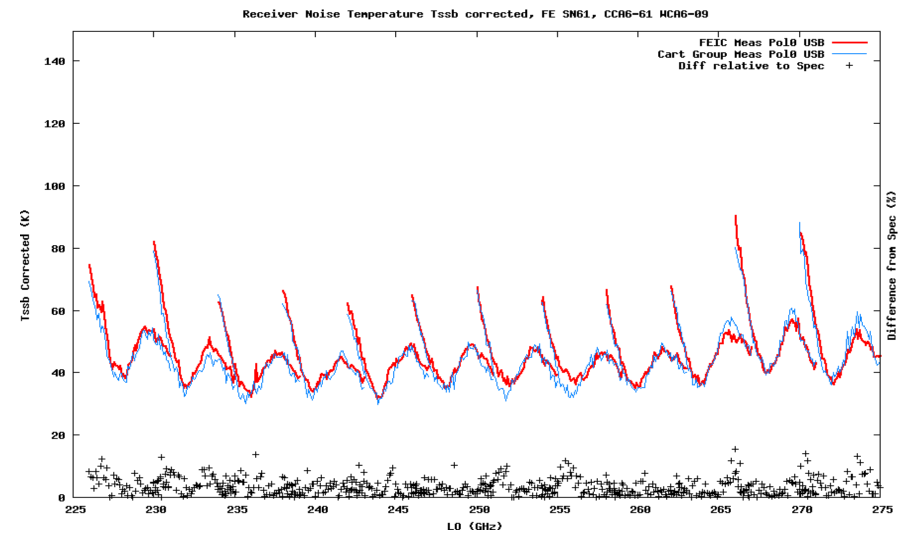

Fig. 1- This plot shows the LO frequency (GHz) vs. the corrected noise temperature for the receiver in the FETMS (red), for the cartridge as tested by the cartridge manufacturer (blue), and the percent difference relative to the specification (black).

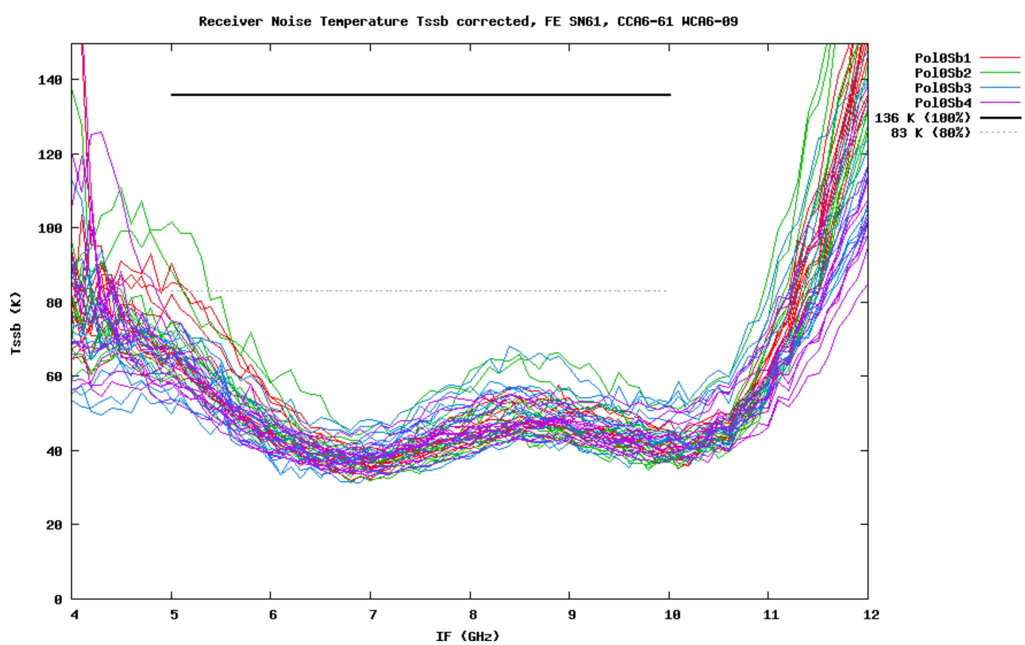

Fig. 2- This plot shows IF signal (GHz) vs. corrected noise temperature (K), for each sideband for each polarization, along with the 100% and 80% specification. Every receiver noise temperature IF curve is shown for qualitative comparison between multiple cartridges of the same band.

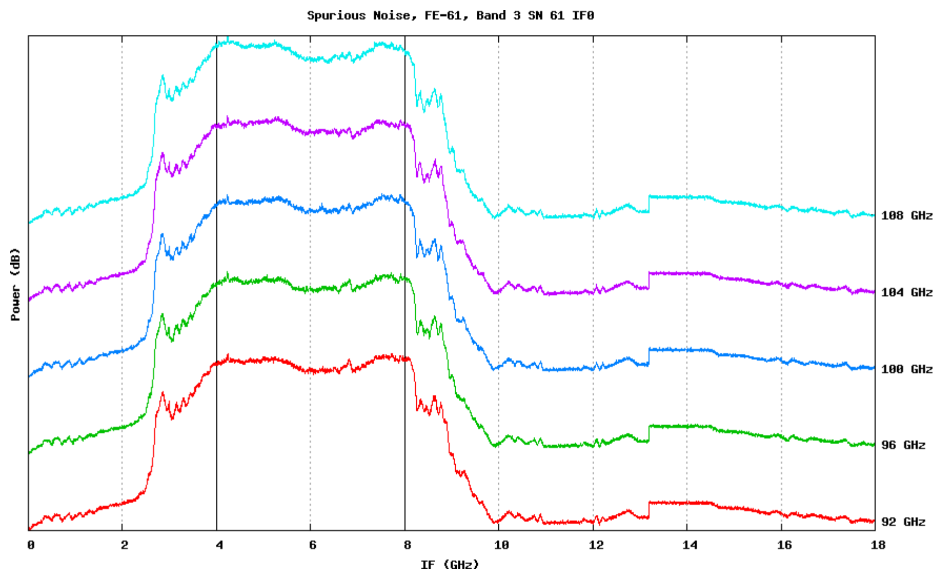

Fig. 3- This plot shows power (dBm) vs. IF (GHz) for band 3, and is looking for spikes and large variations between the desired IF window (4 – 8 GHz). Each LO frequency for the band is represented.

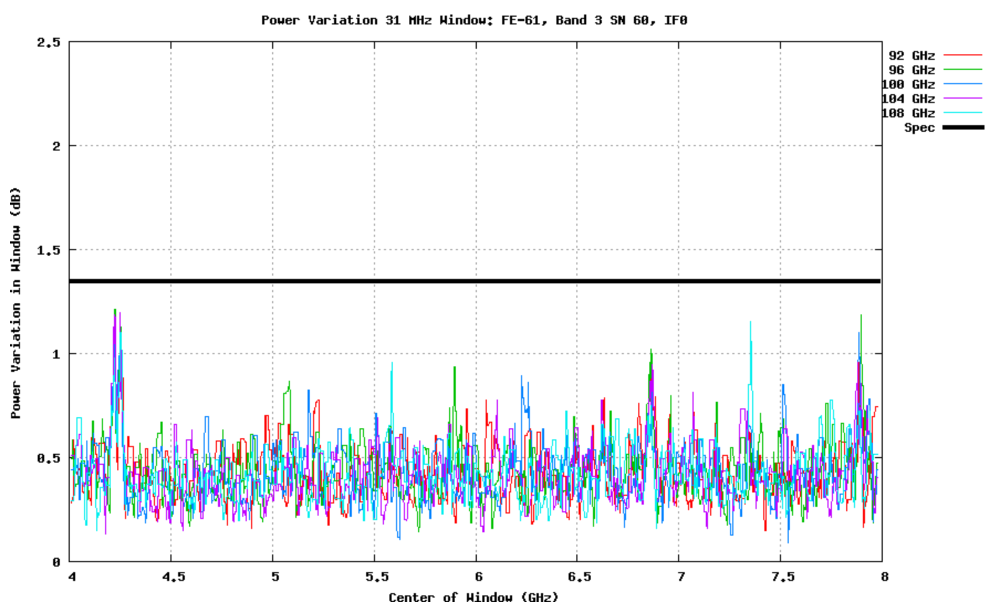

Fig. 4 - This plot shows the power variation (dB) over a 31 MHz window at the center frequency of the window (GHz). Each LO frequency for the band is represented, along with the specification line at 1.35 dB.

3. Test System Structure

This new software library was created in PHP, which is an object-oriented, open-source, server-side scripting language used for web development. The main features of this library are to apply modular coding practices with quality documentation to allow for simple upgrades, quicker maintenance, and greater adaptability.

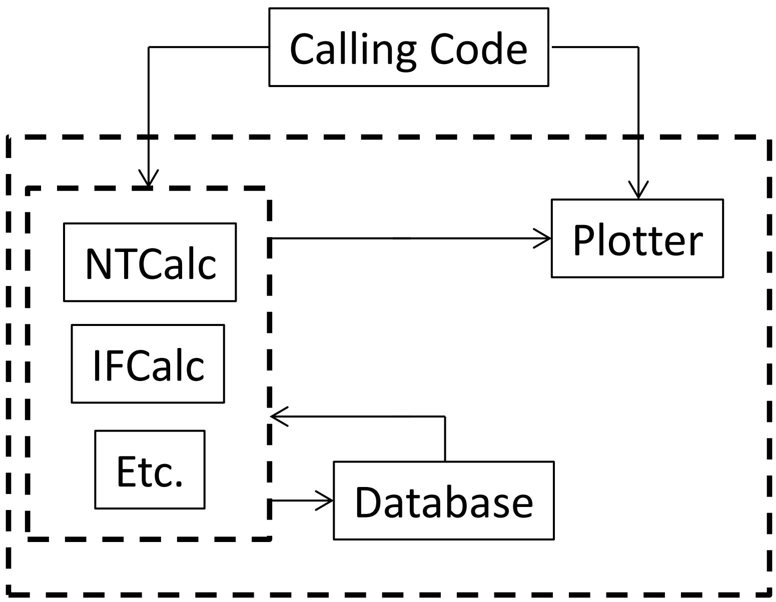

Fig. 5 – Shown is a depiction of the structure of the new FETMS library. The calling code is set on the server and is used to communicate between the user and the library. The box with NTCalc and IFCalc represents the various test and calculation routines used by the FETMS calling code. The database is hosted on a MySQL 5 server, and supplies the test data to the library. The data structures are a direct product of the database or the loaded data from the plotter. The plotter is a module that takes in a data structure, and writes and runs a GNUPLOT script. In addition, the calculation classes, plotter, and data structures can interact with each other.

The structure of this library, which can be seen in Figure 5, is built to allow communication between the various modules and to reduce computing time when running the FETMS. These various modules implement structured interfaces which utilizes various functions to allow each class to communicate smoothly and efficiently. This also gives database retrieval flexibility as a change in the database will not affect the module that calls it. Another feature comes with the universality of the data structure, which is built to accept any data and seamlessly add it into the structure for later use, allowing ease in data manipulation. This is done using PHPs array features which allow data to be categorized by a key, giving a user the ability to add any data to the structure, and easily find it for later use. Finally, the plotter module gives the user a simple interface to create custom plots, like the ones shown above, along with additional data manipulation and storage options. Through various callable functions, the user has access to various plotting options, with very basic GNUPLOT knowledge necessary.

The code includes extensive comments, which gives the user sufficient information on every callable function, along with contributing to making maintenance quick and simple.

4. Deployment and Future Work

The first version of this software library is integrated into the FETMS at the NRAO Technology Center in Charlottesville, VA, and future versions will be sent to ALMA's Operation Support Facility (OSF) in Chile.

Although this library is operational, it still needs to run through a significant amount of case tests, such as running through data from every band, to ensure that any bugs are removed before being used in a production FETMS at the Central Development Laboratory (CDL) and the ALMA OSF. So far, this library only works on noise temperature and IF output spectrum tests ran by the FETMS, but future work will include additional test classes for the WCA, Fine LO Sweep, etc., along with additional callable functions in the plotter module.

Additional specifications and information on the FETMS can be found in Cunningham and Grammer and in Cunningham, Tan, & Rudolf et al, which are referenced below. This software can be found at https://github.com/beaudoi1/ALMA-FETMS/test/ and is free for public use. This project was made possible by the Research Experiences for

Undergraduates (REU) program at the National Radio Astronomy Observatory (NRAO) in Charlottesville, VA.

5. References

Cunningham, C. T., and W. Grammer. *Front-End Sub-System Design Description*. ALMA-40.00.00.00-029-A-DSN. Retrieved from ALMA Engineering Document Management System (EDM).

Cunningham, C. T., G. H. Tan, H. Rudolf, and K. Saini. *Front-End Sub-System for the 12 M-Antenna Array Technical Specifications*. ALMA-40.00.00.00-001-A-SPE. Retrieved from ALMA EDM.